

The University of Chicago

USE OF INSOLUBLE RESIDUES FOR CORRELATION IN OKLAHOMA

A PART OF A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE PHYSICAL
SCIENCES IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY
AND PALEONTOLOGY

1935

By
HUBERT ANDREW IRELAND

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS

Reprinted from
THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Vol. 20, No. 8, August, 1936

The University of Chicago

USE OF INSOLUBLE RESIDUES FOR CORRELATION IN OKLAHOMA

A PART OF A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE PHYSICAL
SCIENCES IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY
AND PALEONTOLOGY

1935

By
HUBERT ANDREW IRELAND

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS

Reprinted from
THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Vol. 20, No. 8, August, 1936



USE OF INSOLUBLE RESIDUES FOR CORRELATION
IN OKLAHOMA

BY

HUBERT ANDREW IRELAND



Reprinted for private circulation from
THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Vol. 20, No. 8, August, 1936

PRINTED IN THE U.S.A.

USE OF INSOLUBLE RESIDUES FOR CORRELATION IN OKLAHOMA¹

HUBERT ANDREW IRELAND²

Chicago, Illinois

ABSTRACT

This paper shows the value of insoluble residues as an important supplement to the methods for determination and correlation of surface and subsurface strata. Beds similar in appearance and composition may be differentiated, a practical value in determining oil structures. A change in lithologic conditions is reflected by a change in residues. Many diagnostic characteristics such as arenaceous *Foraminifera*, silicified fossils, authigenic crystals, sand grains, types of chert, and other residues are liberated, concentrated, and exposed by the solution of the obscuring matrix. The pre-Mississippian formations of central and eastern Oklahoma, from the Arbuckle Mountains to the Ozarks, are correlated by means of residues of samples from wells and outcrops. The beds of the Simpson formation which change rapidly, both laterally and vertically, may be traced readily when studied according to zones instead of separate units. When lateral changes in the type of residue are noted, correlations may be extended for long distances, but not over long intervals between samples.

INTRODUCTION

The purpose of this investigation is to study and describe the insoluble residues of the pre-Mississippian sediments of Oklahoma; to trace and correlate the beds of pre-Mississippian age by means of the residues of well samples and outcrop samples from the Arbuckle Mountains to the Oklahoma part of the Ozark Plateau; to study and describe the arenaceous *Foraminifera* of the pre-Mississippian formations; and to evaluate the use of insoluble residues for subsurface study and correlation.

ACKNOWLEDGMENTS

The writer is especially indebted to Carey Croneis and F. J. Pettijohn of the University of Chicago under whose direction the paleontological and mineralogical work was done.

Special thanks are given to H. S. McQueen of the Missouri Bureau of Geology and to C. A. Merritt of the University of Oklahoma for introduction to the method. V. E. Monnett of the University of Oklahoma provided facilities for the solution and filing of the samples. G. D. Gibson aided greatly in the labor of dissolving several thousand samples.

¹ Manuscript received, May 28, 1936.

² University of Chicago. Home address, 3909 Classen Boulevard, Oklahoma City, Oklahoma.

Thanks are expressed to the various petroleum companies and to the geologists representing them from whom samples were secured, especially to J. T. Richards and Max Littlefield of the Gypsy Oil Company, R. L. Clifton of the Champlin Oil Company, John Ware of the Skelly Oil Company, H. S. Thomas of the Slick Estates, S. W. Lowman of the Mid-Continent Petroleum Corporation, J. C. Finley of the Phillips Petroleum Company, and Zenas Stucky of the Empire Oil and Gas Company.

Acknowledgment is given to J. K. Knox, D. A. McGee, and Norval Ballard of the Phillips Petroleum Company for helpful discussion and aid given during the summer spent in their laboratories.

C. E. Decker kindly made available the residues of the type sections of the Arbuckle and Simpson formations made by C. A. Merritt, which are now on file at the Oklahoma Geological Survey.

L. E. Workman of the Illinois Geological Survey was very helpful with his criticism and suggestions.

DEFINITION OF INSOLUBLE RESIDUES

The term "insoluble residue," as used here, includes all material remaining after a sample has been digested by cold dilute hydrochloric acid. The dilute acid was made by taking equal volumes of water and concentrated commercial hydrochloric acid. The time allowed for digestion varied from 3 to 24 hours. Natural residues are left by weathering, but such residues and those due to solution by reagents other than hydrochloric acid are not considered in this paper. The term "siliceous residue" can not be used for those described here since many of the residues are not siliceous.

LOCATION OF AREA

The region covered by this study is a rhomboid-shaped area in central, eastern, and northeastern Oklahoma covering about 13,000 square miles. The Arbuckle Mountains are in the southwestern part of the area and the Oklahoma portion of the Ozark Plateau is in the northeastern part of the area.

HISTORY AND PREVIOUS WORK ON INSOLUBLE RESIDUES

The first paper dealing with insoluble residues appeared in 1888 by E. Wethered.³ Since that time many workers have used residues for the investigation of various problems. H. S. McQueen⁴ of the Missouri Bureau of Geology was the first to use residues on a large scale

³ E. Wethered, *Geol. Mag.*, Decade III, Vol. 5 (1888), p. 139.

⁴ H. S. McQueen, "Insoluble Residues as a Guide to Stratigraphic Study," *Missouri Bur. Geol. Fifty-Sixth Bien. Rept.* (1931), Appendix.

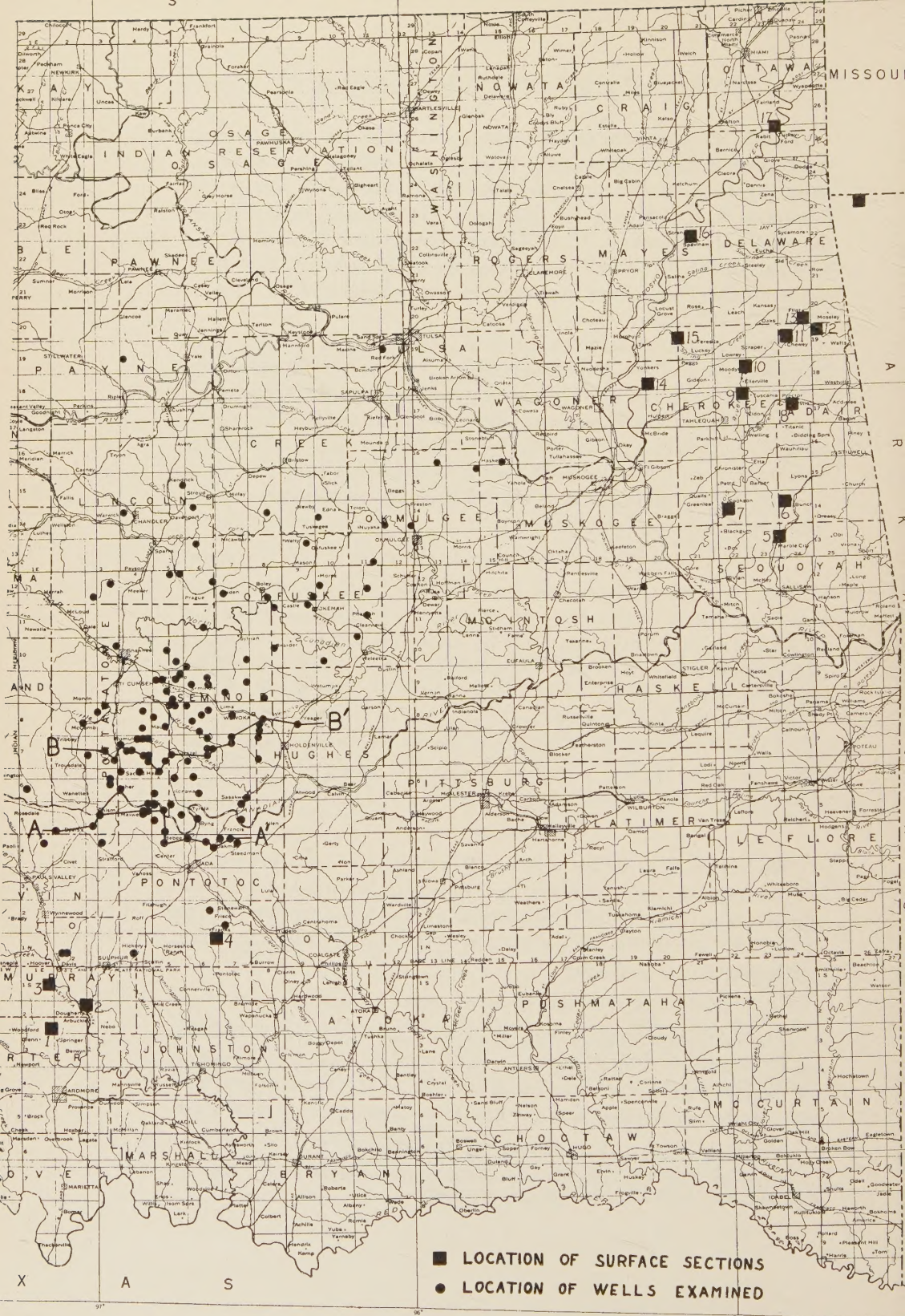


FIG. 1.—Map of central and northeastern Oklahoma, showing location of wells and outcrops sampled for study of insoluble residues; also showing location of cross sections AA' and BB' of Figure 13. Location of surface sections: 1, Tulip Creek; 2, Dougherty; 3, Lisk Creek; 4, Marble City; 5, Muskogee; 6, Muskogee.

for practical correlation purposes. He started his investigation in 1924 and published the results in 1931. At that time he had over 30,000 samples, chiefly from the Cambrian and Ordovician rocks of Missouri. He also studied samples of material from adjacent states in order to extend the Missouri correlations. C. A. Merritt⁵ of the University of Oklahoma has studied the residues from several sections of the Simpson formation and the Arbuckle limestone in the Arbuckle Mountains. J. W. Ockerman⁶ of the Kansas Geological Survey has studied the residues of the Hunton and Viola limestones from samples secured from wells drilled in the vicinity of Topeka, Kansas. L. E. Workman of the Illinois Geological Survey has employed the residue method very efficiently in subdividing the limestone of the Silurian of northern Illinois, but has not published as yet the results of his work. His study includes beds equivalent to Oklahoma beds. G. E. Burpee and W. L. Wilgus⁷ have used insoluble residues for a study of the Permian beds in the Eunice oil field of New Mexico.

PREPARATION OF SAMPLES

Samples were collected at intervals of one foot where possible, but where sandstone or shales occurred they were taken at greater intervals. Altogether, 56 localities were measured in the Ozark area of northeastern Oklahoma and part of the adjacent area in Arkansas. The beds included ranged from Ordovician to Pennsylvanian, but the Mississippian were later omitted as the investigation became too bulky for practical value. Furthermore, the well samples above the base of the Mississippian are chiefly from rotary wells and unsatisfactory to use due to cavings from the overlying beds. The widespread unconformity at the base of the Chattanooga shale was another reason for omitting the Mississippian. In all, 6,300 samples were dissolved and studied, of which about 5,000 were from wells in central and southern Oklahoma.

Well cuttings were taken from rotary and cable-tool wells. The cable-tool cuttings were preferable since they were less contaminated by cavings, but the rotary cuttings were used in order to test the value of all kinds of material. Since most wells in Oklahoma are drilled

⁵ C. A. Merritt and C. E. Decker, "Physical Characteristics of the Arbuckle Limestone," *Oklahoma Geol. Survey Circ.* 15 (1931).

C. A. Merritt and C. E. Decker, "Physical Characteristics and Stratigraphy of the Simpson Group," *ibid.*, *Bull.* 55 (1931).

⁶ J. W. Ockerman, "Insoluble Residues of the Hunton and Viola Limestones of Kansas," *Jour. Sed. Petrol.*, Vol. 1 (1931), p. 43.

⁷ G. E. Burpee and W. L. Wilgus, "Insoluble Residue Methods and Their Application to Oil Exploration Problems," *Min. and Met.* (October 7, 1935).

with rotary tools, the application of the use of insoluble residues is of significance. In many cases, limestone fragments had to be picked out and then dissolved. Since most of the wells have casings set on the Hunton limestone or the Fernvale limestone, the samples below those horizons were generally excellent. Twelve grams of material was used since many well samples have been cut to such a size that a larger amount would destroy the major portion of the available sample. The writer is deeply grateful to the geologists who furnished even a small amount of their irreplaceable material.

The cost of making insoluble residues, including bottles, labels, corks, acid, et cetera was about \$.015 per sample. The time necessary for solution of 12 grams of samples is 2-6 hours, depending on the size of the fragments. Approximately 50-100 samples may be made and studied in one day by one person, depending on the number of beakers available. The following equipment is needed for the preparation and examination of 1,000 samples weighing 12 grams each.

10 gallons of concentrated commercial hydrochloric acid which should be diluted with an equal part of water
3 or 4 dozen 250-cubic centimeter beakers or 10-ounce tumblers
Sand bath or oven for drying samples
7 gross each of 2-dram glass vials, labels, and corks
Binocular microscope and miscellaneous material

In making a residue, the writer used 5-10 cubic centimeters of acid on first treatment; otherwise, the initial effervescence of fine particles would cause loss of material over the edge of the beakers. Then each sample was covered with about 75 cubic centimeters of acid and allowed to stand until effervescence ceased. The fine clay and precipitates were decanted and additional acid applied until complete digestion of soluble matter was insured. Smooth rounded pellets indicated incomplete digestion. After digestion the samples were washed several times to eliminate colloidal clay and fine matter, soluble salts, and all traces of unused acid. Gypsum frequently forms, which obscures the particles when dry. After drying, the residues were bottled, labelled, and filed, and subsequently examined, described, and interpreted. Accurate weighing of the samples was not necessary since well cuttings are not absolutely pure, and accuracy is offset by the contamination. The writer used a graduated cylinder for determining the percentage of residue in reference to the original volume and considered the method satisfactory.

DESCRIPTION OF RESIDUES

The residues may be classed according to their derivation from allogenic or authigenic constituents of the original rock. Allogenic

constituents are those derived from earlier sediments and authigenic constituents are those formed contemporaneously with, or subsequently to, the deposition of the sediment.⁸ The writer uses the term "syngenetic" to include residues from constituents formed contemporaneously with the sediment and the term "epigenetic" to include the residues from constituents formed subsequently.

CLASSIFICATION OF RESIDUES

<i>Allogenic</i>	<i>Authigenic</i>	
	<i>Syngenetic</i>	<i>Epigenetic</i>
Silt Sand Shale fragments Mineral fragments	Fossils Chert Glauconite Pyrite Dolocasts formed from dolomite crystals	Replaced fossils Chert Quartz crystals Anhydrite crystals Siliceous oölite Interstitial silica Pyrite Dolocasts formed from dolomite crystals

ALLOGENIC

The sand grains are chiefly quartz, though feldspar and various heavy minerals occur in small amounts. Heavy minerals were not especially investigated in this study. The sand grains are frosted, subangular to rounded, and range from 0.05 to 1.2 millimeters in diameter. Many grains with an etched surface were seen; others were somewhat polished. Considerable sand occurred which had been frosted after secondary enlargement of the grains. The prism angles were still observable though somewhat rounded. Several samples exhibited polished rounded sand grains which varied from 0.05 to 0.4 millimeter in diameter. Anderson⁹ has shown that frosting occurs more readily from scour in agitated water than by wind action. The polished grains were probably rounded by scour but were polished in gently agitated water.

Sand grains enlarged by secondary addition of silica are very common in the residues. The degree of enlargement grades from incipient crystals to well formed prisms and pyramids, and in some cases to tightly locked grains where crystal faces are distorted by the pressure of growth. Many of the crystal faces show multiple facets. Although the growth is due to secondary causes, the sand grains are allogenic

⁸ P. G. H. Boswell, *Mineralogy of Sedimentary Rocks*, Thomas Murby and Company, London (1933), p. 1.

⁹ G. E. Anderson, "Experiments on the Rate of Wear of Sand Grains," *Jour. Geol.*, Vol. 34 (1926), pp. 144-58.

and when they occur in a residue they must be classed as grains derived from allogenic constituents.

One type of secondary enlargement is found, which seems so unusual that a description of it is given (Fig. 2). The sand grains show many minute elongated prisms of quartz extending from the surface of the grains. The grains are very rough, appear frosted, and the secondary growths appear to radiate. However, all the prisms attached to a single grain have the same extinction and optical orientation of the parent grain. The sand grains are found in quantities of less than one

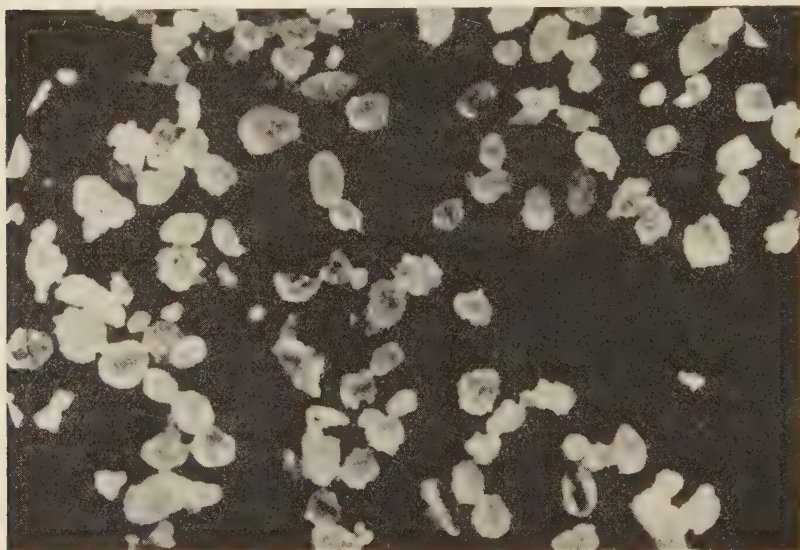


FIG. 2.—Phenomenal secondary growth of sand grains with numerous tiny elongate crystals oriented optically with parent grain and giving very rough frosted appearance. From base of exposure of Cotter dolomite at White River bridge east of Rogers, Arkansas. ($\times 20$)

per cent in beds where other evidence of the addition of silica as chert and replaced fossils is lacking. The grains are best shown in samples taken from the base of the Yellville (Powell and Cotter) at the bridge on White River near Rogers, Arkansas. Similar grains are found in abundance in the Arbuckle limestone. All occurrences so far have been from dolomite and limestone of Ozarkian and Canadian age.

Most of the fine particles of silt and clay are decanted when the residues are washed. However, aggregates of silt remain. Buff to white silt aggregates are typical of the middle part of the Hunton formation.

Shale fragments are common as residues since shales are largely insoluble. Shale fragments which are used as diagnostic of a certain

bed must be carefully distinguished from other fragments of shale which may be due to caving. Many of the shales have peculiarities such as dolocasts, casts of fossils, inclusions of pyrite or carbonaceous matter, and embedded sand grains which with the color, texture, and bedding make it possible to identify them.

Fragments of igneous rock, which were decayed but not disintegrated, were observed in several well samples. Chlorite, tourmaline, granular quartz, augite, feldspar, hornblende, and biotite were found. These occurred in a zone about 25 miles wide, extending about 100 miles northwest from the vicinity of Ada, Oklahoma. The fragments were found throughout the Fernvale and in the upper part of the Hunton formation, generally near the top of each.

SYNGENETIC

The glauconite needs no special description as its character and its origin were probably similar to those of the Tertiary greensands of the Atlantic and Gulf coasts.¹⁰ The fossils found as residues are chiefly arenaceous *Foraminifera* and are described in another part of this study. Sponge spicules and casts of many other forms are present but have no particular significance. It is well to mention that the worm jaws found commonly in many of the equivalents elsewhere of the formations studied here are not present in the residues.

Dolocasts and chert are discussed in full under the residues derived from epigenetic constituents of the formations.

EPIGENETIC

Organisms are replaced by silica, pyrite, and glauconite, but the siliceous replacement is by far the most common. The replacements may be in the form of acicular crystalline flakes, as concentric nodular growths, vitreous quartz, or chalcedony. The nodular growths resemble siliceous oölite, but the writer has definitely identified them as replacements of organic matter by dissolving several partially replaced brachiopods which yielded the nodules.

Minute quartz crystals with well developed pyramids at both ends are commonly found. The crystals are about 0.03 millimeter in diameter and 0.1-0.15 millimeter in length. The crystals are considered as authigenic in origin¹¹ and occur chiefly in dolomite in quantities of less than one per cent of the original sample. Nineteen of the 20 occurrences were in the "Dense" limestone and, in this study, are diagnostic of that bed.

¹⁰ W. H. Twenhofel *et al.*, *Treatise on Sedimentation*, Williams and Wilkins, Baltimore (1926), p. 339.

¹¹ P. G. H. Boswell, *op. cit.*, p. 96.

Minute crystals and fragments of anhydrite occur in the Hunton in many wells northeast of Seminole. The material is colorless and is petrographically identified as anhydrite, although that mineral is not listed by Boswell¹² as an authigenic mineral. Where found it generally occurs in abundance rather than as a few scattered crystals.

Pyrite is found in all beds and is not a diagnostic residue except where large quantities form the major part of the sample. Pyrite is often found instead of chert in the lower part of the Hunton formation where it constitutes 30–80 per cent of a total residue of 2 per cent or less. Tiny crystals of pyrite are found embedded in shale and chert. The pyrite is helpful in noting unconformities. The porous zone of the erosional surface allowed free circulation of water containing iron and sulphates during the time of erosion or facilitated such movement later. The presence of limonite has no significance except that it is related to the pyrite.

When dolomite replaces lithified limestone, crystals of dolomite are formed with cavities between them caused by a reduction in volume during the chemical change.¹³ These cavities when filled by silica form a lacework of interstitial silica after the dolomite crystals are dissolved.

Siliceous oölite is not common, but it is occasionally found at the base of the Chimney Hill limestone whenever the calcareous oölite at the horizon has been replaced. The oölites are also common in the middle part of the Arbuckle limestone from 3,000 to 4,050 feet below the top of the type section along U. S. Highway 77 where it crosses the Arbuckle Mountains.

Dolocasts¹⁴ are rhombohedral cavities formed by the solution of dolomite crystals from an insoluble matrix, such as chert, pyrite, glauconite, or shale. The term "calccasts" might also be used if it could be determined that the cavities at one time held calcite rather than dolomite crystals. The cavities were formerly called dolomolds by the writer. However, if the crystal is considered as being the mold and the matrix as being deposited around it, then the term dolocast is preferable. The dolocastic cavities in pyrite and glauconite are on the surface and are not found within the fragment.

The dolocasts are found chiefly in chert associated with beds of dolomite (Fig. 7). The cavities may be due to the deposition of secondary chert around the dolomite crystals. They may also be due to the solution of the original crystals which were included in the silica gel

¹² P. G. H. Boswell, *op. cit.*, p. 7.

¹³ W. H. Twenhofel *et al.*, *op. cit.*, p. 261.

¹⁴ H. S. McQueen, *op. cit.*, p. 9.

TABLE I

Age		Arbuckle Mountains	Central Okla. (Subsurface)	Subsurface by Residues	S. W. Ozark Region	S. E. Missouri
Mississippian	Upper Devonian					
Middle Devonian	Hamilton					
Lower Devonian	Onondaga					
Lower Devonian	Oriskany					
Upper Devonian	Helderberg					
Upper Devonian	Silurian					
Middle Silurian	Niagara					
Lower Silurian	Alexandrian					
Upper Ordovician	Richmond					
Middle Ordovician	Trenton					
Lower Ordovician	Black River					
Lower Ordovician	Chazy					
Lower Ordovician	Beekmantown (Canadian) *					
Upper Cambrian	Ozarkian					
Upper Cambrian	Reagan ss.					
Middle and Lower Cambrian						
Pre-Cambrian	Tishomingo granite					

before lithification. The dolocasts are remarkable for the sharp outline of the crystal form. Crystalline chert from the base of the Hunton formation in the Colton-Ellington well in Sec. 25, T. 12 N., R. 19 E., shows a few dolocasts. The cavities are from crystals of dolomite which were originally lodged between projections of the growing quartz prisms. The dolomite existed before the infiltration of the silica; the silica was deposited around the dolomite crystals. Glauconite embedded in the chert also indicates that the chert was deposited later.

Next to sand, chert is the most common residue and is of more diagnostic value. Texture, color, transparency, luster, and crystalline character are the factors which form the basis for distinguishing between the several varieties. A dark brown sucrose chert occurs as a good marker for the "Dense" limestone in the southern part of the area studied. However, a similar chert is found in a lower horizon. The microgeodic, drusy, and crystalline texture gives the appearance of aggregates of brown sugar. Another chert with a dull luster and speckled with minute limonite or pyrite granules gives a pepper-like appearance to residue from the middle part of the Bromide formation in the wells just north of the Arbuckle Mountains. Another chert of importance has a granular texture and a buff or brown color. The granules are uniform in size, composed of silt, and cemented by chalcedony. Dense, sharp, milky, opaline chert occurs abundantly, most of it probably due to the replacement of organisms.

DESCRIPTION OF ZONES AND FORMATIONS IDENTIFIED

BY RESIDUES

HUNTON FORMATION

The Hunton formation, where all members are present, may be divided into three general zones on the basis of residues, and where arenaceous *Foraminifera* are present it may be divided into four zones.

The top member is identified by subsurface geologists as the Bois d'Arc limestone and is described as dense, white cherty limestone. The insoluble residues are milky white, dense chert with small amounts of sand grains and replaced organisms. The residue after solution varies from 1 to 100 per cent of the original volume, but is generally less than 10 per cent. In some places a large amount of sand produced by caving of the overlying Misener sand is noticed. The limestone is absent in most wells due to an unconformity, but occurs in nearly all wells in T. 7 N., R. 4 E.

The Haragan limestone and the Henryhouse limestone below it form the middle part of the Hunton. They are separated by a discon-

formity which is difficult to identify. Both formations are represented in the insoluble residues by varying amounts of pitted soft aggregates of silt, in places with a small amount of sand, chert, or siliceous fossil fragments (Fig. 3). The occurrence of the silt is remarkably persistent making the recognition of the Haragan and Henryhouse possible in most of the area studied. The percentage of the silt is not diagnostic since in both limestones it varies in amount from 1 to 60 per cent of the dissolved sample with an average of about 10 per cent. *Foraminifera* are rarely found in the Haragan but are common in the

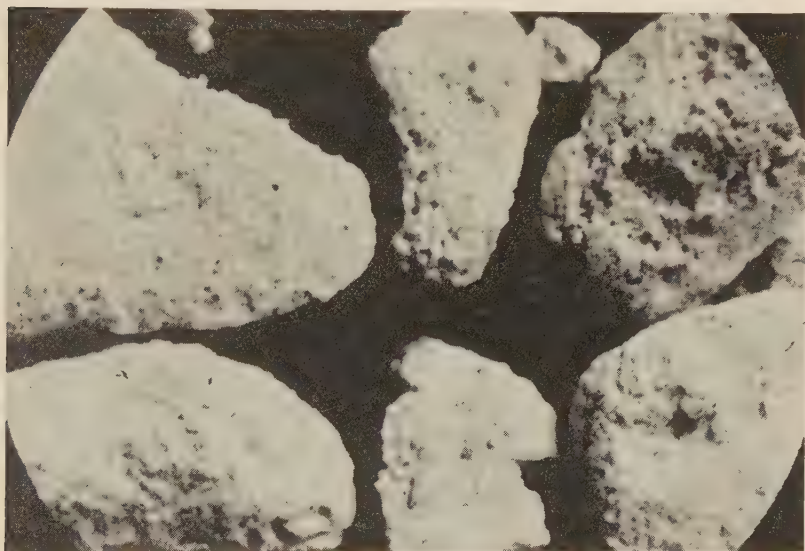


FIG. 3.—Typical Hunton silt aggregates found in Haragan and Henryhouse limestones. Depth, 2,270 feet in Dixie-Norman No. 1, Sec. 13, T. 5 N., R. 4 E. ($\times 20$)

Henryhouse and, where found, make it possible to separate the two beds. In many of the wells northeast of Seminole a small sand residue prevails in place of the usual silt. The percentage of the residue is less than one per cent, indicating a limestone. In the Continental Oil Company's Allred well, Sec. 28, T. 10 N., R. 7 E., a bed 10–15 feet thick containing as much as 100 per cent chert, occurs above the silt-bearing zone. The cherty bed does not represent the Bois d'Arc but is probably in the upper part of the Henryhouse limestone. The abnormal amount of chert locally was probably deposited from the circulating ground water beneath the overlying impervious Chattanooga shale. The erosion of the Hunton before

the Mississippian has probably made it sufficiently porous for free circulation.

The thickness of the Haragan and Henryhouse in the Arbuckle Mountains varies greatly in short distances. Erosion of the Henryhouse developed a relief which makes the Haragan thin on top of the ancient hills and thick in the valleys. The residues from the subsurface samples indicate a much smaller relief and a constant thickening of the Henryhouse northeast until it merges with the Chimney Hill

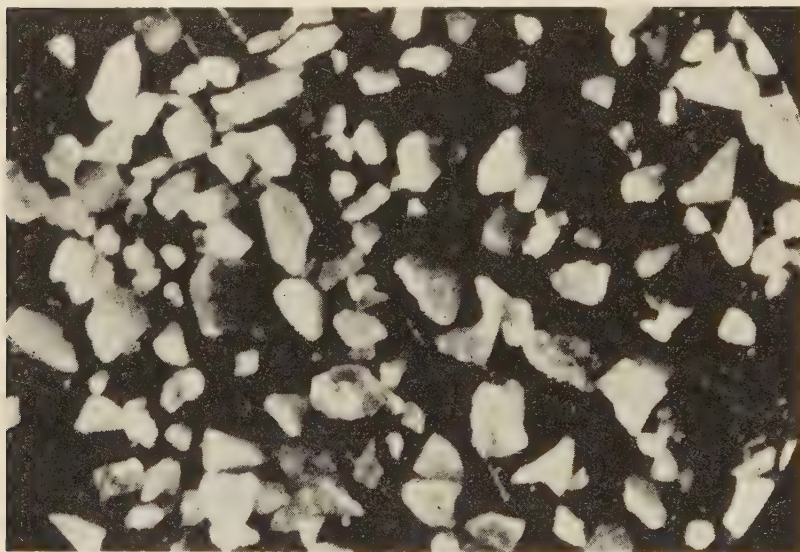


FIG. 4.—Dense white sharp chert from Chimney Hill limestone. Depth, 3,873 feet, Prairie-Palmer No. 1, Sec. 2, T. 11 N., R. 9 E.

to become the St. Clair limestone. The Haragan is thin on the subsurface section and is eventually truncated near a line from Muskegee to Okemah and Chandler.

The lowest member of the Hunton encountered in wells is the Chimney Hill limestone. The chief characteristic residues are abundant arenaceous *Foraminifera*, abundant white, dense chert, vitreous in part, and siliceous replacement of fossils (Fig. 4). The chert is usually absent in the area of the Seminole, Little River, Maud, and Earlsboro pools and the residues are composed of abundant pyrite and small amounts of sand. All residues of the Chimney Hill are generally less than 5 per cent of the original samples. Where the middle glauconitic

member of the Chimney Hill occurs, the glauconite is in addition to the usual chert or pyrite. Siliceous oölite is present in some places at the base of the limestone. Fossil replacements are common and appear as white crystalline fragments, nodules, and acicular fragments.

The beds bordering the "Seminole inlier" do not contain the typical Chimney Hill residues. The absence of the typical residue, and therefore the absence of the Chimney Hill, is considered as evidence that the uplift allowing the area to be eroded was continuous, probably coincident with the slowly rising Ozark dome. The Chimney Hill limestone was probably laid thinly across the "inlier" and eroded during the uplift and later, thus allowing the Henryhouse to be deposited in contact with the Sylvan shale in some areas and in normal contact with the Chimney Hill limestone in other areas. The remarkable similarity of some of the silt of the Henryhouse to the silt of disintegrated Sylvan shale suggests the erosion of shale as the origin for part of the Hunton silt aggregates.

The residue from the Hunton in the Colton-Ellington well in Sec. 25, T. 12 N., R. 19 E., is nearly all sand which is so similar to the sand of the Fernvale that the identification of the Hunton is impossible on that basis. The presence of dolomite crystals, which are very unusual in the Hunton, further confuses the identification. However, the typical glauconite and the crystalline chert of the Chimney Hill occur at the base of the formation and identification is thus possible. The Fernvale here is unusually characteristic so that it could not possibly be mistaken for the Hunton limestone.

The thickest section of the Hunton which has been drilled occurs in Sec. 7, T. 7 N., R. 4 E., and measures 350 feet. The Silurian portion, as defined by silt aggregates and fossils, is 250 feet thick and is chiefly limestone. The Haragan is 75 feet thick and has small amounts of chert. It is distinguished from the Bois d'Arc which has large amounts of chert. The Henryhouse and Chimney Hill limestone are 295 feet thick and the Haragan limestone only 15 feet thick in Independent Oil and Gas Company's Leclair No. 1 in Sec. 23 of the same township. The Chimney Hill, as usual, is marked by the low percentage of the residue composed of pyrite, chert, glauconite, and sand grains. The Silurian remains similar in thickness in the wells of Ts. 8 and 9 N., Rs. 2 to 7 E., although in places all of the Hunton is eroded. Wherever the Hunton is thin, it is composed of the lower beds, showing that the thinning is due to erosion. The only exception would be the area adjacent to the "Seminole inlier."

The thicknesses at the outcrops are as follows.

Formation	Thickness in Feet			
	Dougherty	Franks	Lick Creek	Tulip Creek
Frisco.....	—	20	—	—
Bois d'Arc.....	12	25	—	2
Haragan limestone.....	38	27	—	60
Haragan shale.....	95	48	10	120
Henryhouse shale.....	47	20	60	104
Chimney Hill limestone....	22	23	12	33

The residues from the surface samples at Dougherty, Lick Creek, and Tulip Creek, along U. S. Highway 77 in the Arbuckle Mountains, may be readily recognized in the subsurface samples. The section at Dougherty has the most representative set of residues. The surface section at Franks, southeast of Ada, Oklahoma, does not show the typical residues, but the arenaceous *Foraminifera* there serve as the diagnostic element. Franks is the only place where Devonian *Foraminifera* are common. The *Foraminifera* of all the surface sections in the Arbuckles are excellent and are very useful in the subsurface study.

The St. Clair limestone in northeastern Oklahoma contains the typical Hunton silt aggregates and *Foraminifera* but in very minor quantities.

SYLVAN SHALE

The Sylvan shale is nearly 100 per cent insoluble and the bed was not studied extensively. The treated samples show gray to blue-green shale composed of fine granular silt and other fragments with layers of fine even-bedded clay. Many of the fine layers are pitted with dolocasts. A dark brown finely doloclastic shale occurs in the lower 5-20 feet. These doloclastic fragments are important as they indicate the approximate top of the Fernvale.

FERNVALE AND SIMPSON FORMATIONS

The following zones were first defined in the southern part of the area, in Pontotoc and Seminole counties. The zones may be traced northward and eastward showing gradual variation in the appearance of the residue. The same horizons could not be correlated if the gradations were not observed. Local lenses of sandstone and green shale and other variations make some zones appear different from the same zone elsewhere. These conditions should be considered when the sections are examined.

Zone 1.—Zone 1 is the Fernvale limestone, frequently called the "Viola." The top of the limestone has one of the most constant residues (Fig. 5). A few fragments of acicular white fossil replacements mixed with some of the pitted brown shale of the overlying Sylvan shale can be depended on as a marker for the top of the Fernvale except in the surface sections and adjacent wells of the Arbuckle area. The top part of the "Viola" in Peckham *et al.* Adams No. 1 in Sec. 11,

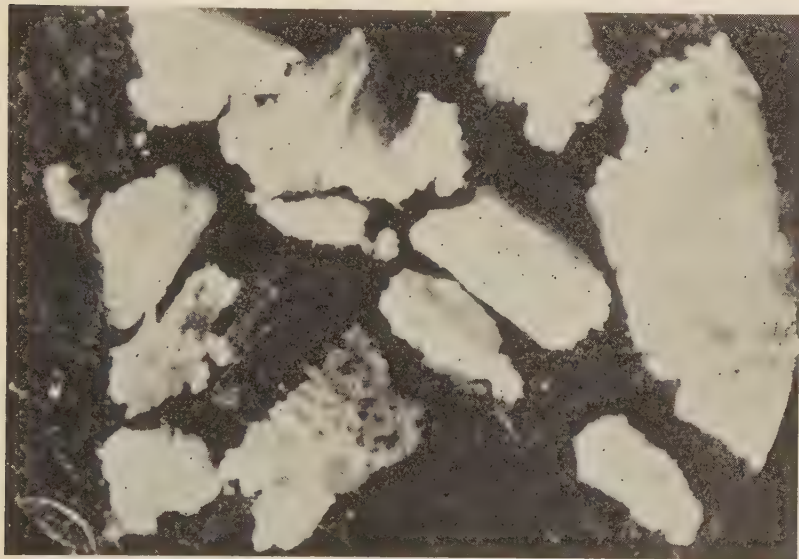


FIG. 5.—Siliceous replacement of fossils found at top of Fernvale limestone. Depth, 3,395 feet, Watchorn-Weldfeldt No. 1, Sec. 30, T. 6 N., R. 5 E. ($\times 20$)

T. 4 N., R. 1 E., contains 160 feet of dense white chert and siliceous replacement of fossils. This does not represent the Fernvale, but the middle part of the true Viola which is not found far north of the Arbuckle Mountain area. A similar situation exists in the Moore Oil Company's Wirick No. 1 in Sec. 29, T. 2 N., R. 7 E. A persistent subzone of the Fernvale with sand grains and occasional quantities of pyrite occurs 10–30 feet below the top of the Fernvale. Neither sand nor pyrite exists in quantities greater than one per cent of the dissolved sample. The sand is relatively uniform in size, 0.2–0.3 millimeter in diameter, but is variegated in character. Some of the grains show incipient enlargement, others more advanced enlargement. The grains are chiefly sub-angular with some frosting and occasionally secondarily enlarged grains which have been frosted.

Zone 2.—Zone 2 is the “Dense” or “Lithographic lime” as described by most subsurface geologists. The bed is 5–50 feet thick and contains 1–50 per cent residue. The characteristic residues are dense brown or drusy crystalline sucrose chert with occurrences of dense or crystalline, white and buff chert. A small amount of detrital sand is ordinarily found. A granuloid brown chert is found in some wells. Similar chert is found at other horizons in a few wells but, as a rule, the foregoing cherts are distinctive of the zone.

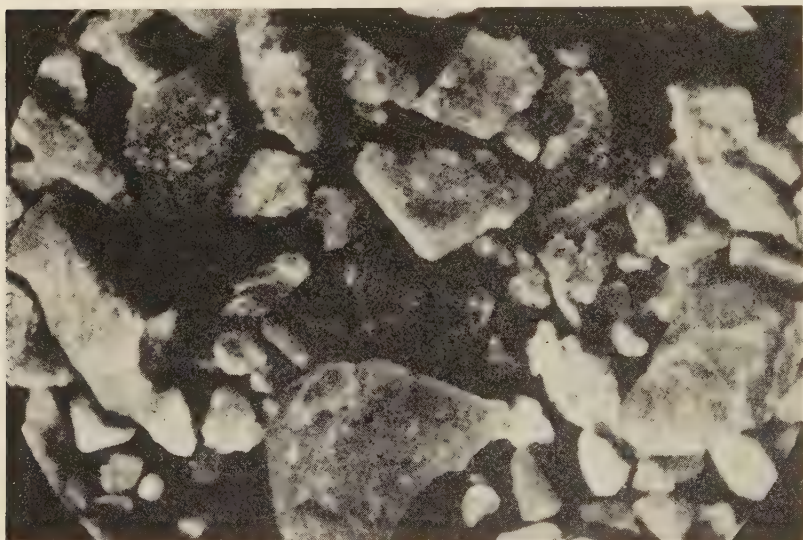


FIG. 6.—Brown sucrose chert from upper dolomite of zone 3 at top of Bromide formation. Depth, 4,098 feet, Watchorn-Zöller No. 1, Sec. 5, T. 6 N., R. 5 E. This chert also found in “Dense” of zone 2, or at top of cherty dolomite.

Minute authigenic crystals of quartz, where found, are a distinctive residue. The crystals are individual with pyramids at both ends of the prism and are 0.03 millimeter in diameter and 0.10–0.15 millimeter in length. The crystals were found in nineteen wells just below the chert horizon except in one well where they were found just below the interval for the absent chert. The “Dense” limestone is not cherty in the Independent Oil and Gas Company’s Asher No. 1, Sec. 3, T. 4 N., R. 4 E., but has green shale and detrital sand similar to the Fernvale. Most of the residue northeast of T. 7 N., R. 4 E., is sand and the green shale is softer and more blue-green in color than the lower Simpson shales.

Zone 3.—Zone 3 is considered by the writer to be the top of the Simpson. It is the horizon of the upper part of the First dolomite. The horizon is markedly a zone of small residue, usually containing less than one per cent and rarely more than 5 per cent. The material is variable being composed of detrital sand, gray or green unevenly bedded shale flakes, variegated chert, or organic replacement. The zone is entirely green shale in Gillespie's Taylor No. 1 in Sec. 12, T. 5 N., R. 4 E., where 1-4 per cent shale is contained in a dissolved



FIG. 7.—Dense brown chert with dolocasts from zone 4 in Bromide formation. Depth, 4,583 feet, Lipka-Finnigan No. 1, Sec. 11, T. 8 N., R. 4 E. ($\times 20$)

sample; however, 20 per cent shale occurs in one sample. The chief criteria for the zone are the position below the "Dense" and the small residue in contrast to the large residue of chert above and below it. The zone varies from 30 to 100 feet in thickness and lenses out north-east between zones 2 and 4.

Zone 4.—Zone 4 is characterized by large amounts of chert varying from 1 to 80 per cent of the residue, but generally having 5-20 per cent. In the wells of southern Seminole County the chert is pepper-like, lusterless, and speckled, grading laterally into white or buff, rough, weathered-appearing chert, slightly speckled. Unfortunately this zone, in many wells of the southern part of the area, also has brown drusy sucrose chert and dense, brown greasy-appearing chert similar to zone 2. However, the sequence of other residues above

generally separate it from zone 2. Dolocasts are common in this zone, both in chert and in dark brown siliceous lacework. Detrital sand of rounded frosted grains and secondarily enlarged grains occur. A few streaks of green shale also exist. The thickness of the zone is 20–150 feet with an average of 100 feet in the southern part, 50–60 feet in the central part, and less than 50 feet northeast of Seminole. It is difficult to identify this zone with only a few samples since the chert is too variable to be of diagnostic value. By the vertical, associated



FIG. 8.—Typical, rounded, frosted, uniform sand grains of Seminole sand. Depth, 4,292 feet, Sunray-Burbonnais No. 1, Sec. 28, T. 7 N., R. 5 E. ($\times 20$)

beds, the large amount of chert, and the presence of dolocasts, the zone may be defined. This zone includes the lower part of the First dolomite and the larger part of the Second dolomite.

Zone 4 in the Seminole area may be divided into three subzones. Subzone 4a is marked by the cherty residues from the lower part of the First dolomite. The Seminole sand is subzone 4b. The cherty residue of the upper part of the Second dolomite, which is below the Seminole sand, indicates subzone 4c. The Seminole or First “Wilcox” sand is a sandstone lense 0–80 feet thick, which exists as a substitute for part of the dolomite, for where the sandstone is thicker the dolomite is thinner. The sand is not found south of Seminole County. The sand grains are well rounded, frosted, and of relatively uniform size averaging 0.2–0.5 millimeter in diameter.

Zone 5.—Zone 5 is chiefly a green shale zone with a few lenses of dolomite which have a chert residue. The shale is soapy appearing, fine-grained, and in many places has embedded sand grains of the St. Peter type, dolocasts, and fossil molds. Much of the shale is dense, hard, and fine-grained. Some of the shale is brown or gray. The samples range from a chert residue of one per cent to a shale residue of 100 per cent, showing that the zone varies from dolomite to shale. The shaly character is distinctly the dominant feature. Siliceous or-

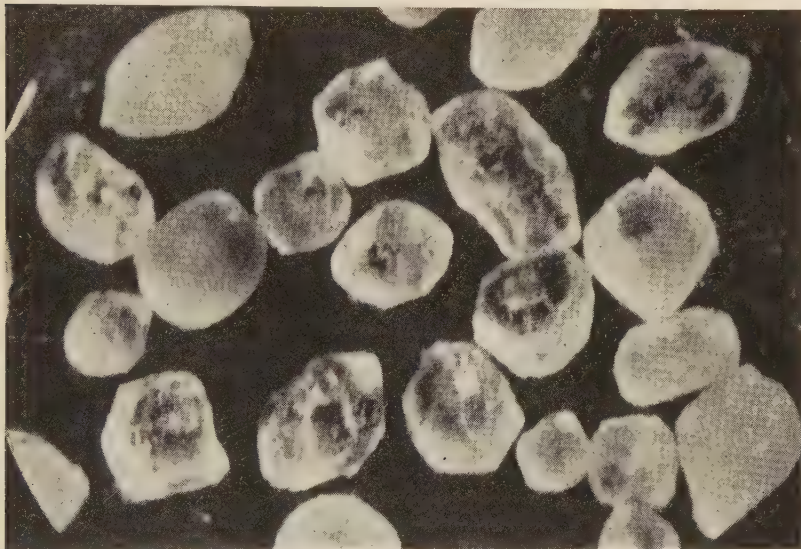


FIG. 9.—Well advanced secondary growth of quartz on large sand grains from top of "Wilcox" sand. Depth, 3,120 feet, Prairie-Fleming No. 1, Sec. 1, T. 5 N., R. 4 E. ($\times 20$)

ganisms from the dolomite beds within the zone are common and with chert form as much as 50 per cent of the residue in some samples. In such samples, however, the total residue is generally less than 40 per cent of the original sample. The thickness varies from 50 to 118 feet. The green shale zone is a marker for the underlying "Wilcox" sand. Zone 5 is the lower part of the Second dolomite.

Zone 6.—Zone 6 is the Second "Wilcox" sand. The Sinclair Petroleum Company's Gardner well in Sec. 6, T. 4 N., R. 6 E., had 625 feet of sand. Weirich¹⁵ reports 900 feet as the maximum thickness near Pauls Valley.¹⁶ The sand is recognized by the large

¹⁵ T. E. Weirich, "Simpson of Central Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), p. 1510.

¹⁶ Fanny Carter Edson calls attention to the fact that the "Wilcox" thicknesses here mentioned are the two thickest sections known. "They are the exception rather

grains at the top, 0.6–1.0 millimeter in diameter, which vary from rounded frosted grains to clear angular grains in the advanced stage of secondary enlargement. Lower in the formation the grains are smaller and variable in appearance. Correlations on the basis of the sand content is hazardous. Streaks of green shale with embedded grains occur.

A peculiar type of vitreous silica was found as part of the Second "Wilcox" sand in the Tidal Oil Company's King well in Sec. 14, T. 10

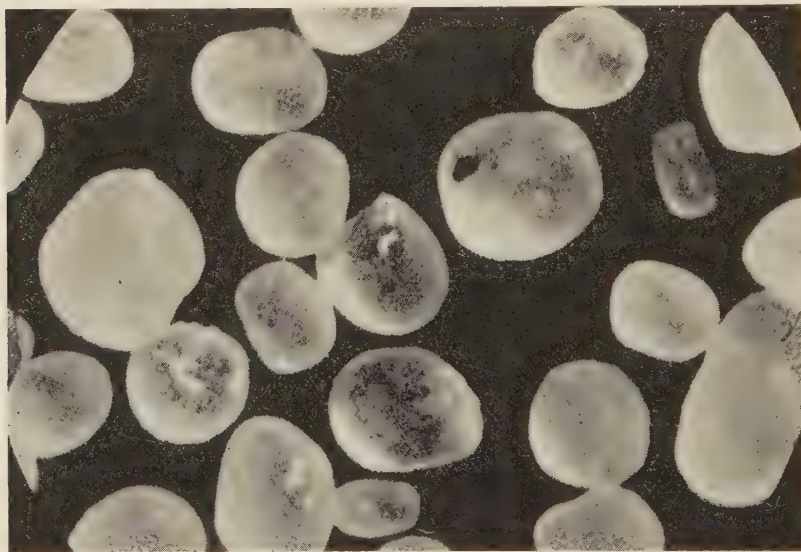


FIG. 10.—Large, well rounded, frosted sand grains from "Wilcox" sand. Largest grain 1.10 millimeters in diameter. Depth, 5,485 feet, Calcul-Wilson No. 1, Sec. 9, T. 8 N., R. 5 E. (×20)

N., R. 8 E. (Fig. 11). The fragments show clear rounded sand grains embedded in milky vitreous chert. McQueen¹⁷ found the same type of chert in the Cotter formation of Missouri. George Rust¹⁸ found nodular chert with sand grains embedded in the Powell formation near Weingarten, Missouri. The sand occurred in layers concentric to the

than the rule. The apparent very great thickness in these two wells (it is not all "Wilcox" sand) is probably due to exceptional, local depositional conditions. For that reason, it would be better to cite the Gypsy Oil Company's Barkus well No. 9, Sec. 6, T. 8 N., R. 6 E., to indicate the general thickness of the 'Wilcox' sand, because this well penetrated the 'Wilcox' sand (70 feet), the pre-'Wilcox' Simpson section (600 feet), and drilled 1,223 feet into the 'Arbuckle' limestone. This well, located in the Seminole region, had a normal 'Wilcox' thickness."

¹⁷ H. S. McQueen, *op. cit.*, p. 23 and Pl. VIIB.

¹⁸ George Rust, personal communication.

exterior of the nodule. A thin section shows sand grains of rounded quartz and some microcline surrounded by a distinct halo of chalcedony which was coarser-grained than the fine matrix of chalcedony. The haloes were circular and not parallel with the outline of the sand grain, being broader where indentations and cavities occurred. One explanation is that the sand grains were collected into balls of silica gel as the gel was moved about on the bottom during the deposition of the Powell formation. Layers of sand were added to the gel ball as it

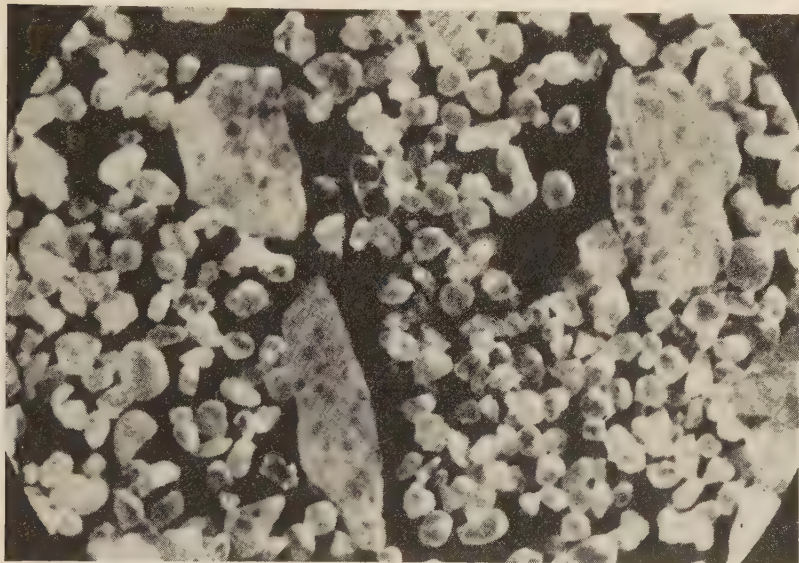


FIG. 11.—Fragments of sand cemented with milky, transparent silica associated with sand grains uncemented from Simpson formation. Depth, 4,294 feet, Tidal-King No. 1, Sec. 14, T. 10 N., R. 8 E. ($\times 20$)

grew larger by aggregation or coalescence with other silica, thus explaining the concentric banding. The type of chert is not confined to a definite horizon since it occurs in the Powell, Cotter, and Roubidoux formations of Missouri, and in the Simpson formation of Oklahoma.

In the Sinclair Petroleum Company's Gardner well in Sec. 6, T. 4 N., R. 6 E., the only well studied, which passed through the "Wilcox" sand, the sand was 625 feet thick; below it was 103 feet of green shale, then 50 feet of sandstone and shale, and at the bottom 77 feet of sandstone. It is quite probable that the Arbuckle limestone would have been encountered within the next 100 feet. These pre-"Wilcox" beds are known as the lower Simpson. The residues are all sand grains and shale fragments.

The residues of the Arbuckle limestone were studied from the Gypsy Oil Company's Barkus No. 9, Sec. 6, T. 8 N., R. 6 E., but since no other Arbuckle samples were available, the residues are not discussed. The samples above the Arbuckle were not obtainable.

CORRELATION

HUNTON FORMATION

The subdivision of the Hunton formation essentially as it exists to-day has been made by Reeds.¹⁹ Maxwell²⁰ is expecting to publish new data for changes in the subdivision in the near future. The Frisco and Bois d'Arc limestones are Oriskany; the Haragan limestone is Helderberg; the Henryhouse limestone is Niagaran; and the Chimney Hill limestone is Alexandrian.

The Frisco limestone is known only at the surface in the north-eastern part of the Arbuckle Mountains and near Marble City in northeastern Oklahoma. Neither residues nor lithologic features indicate its presence in wells.

The Bois d'Arc limestone is coarse-grained and cherty at the outcrop. It has a large amount of chert as a residue and is recognized on this basis where the chert overlies the typical silt aggregates of the Haragan beds below. North of the Arbuckles, dense, white, opaline chert or fossil replacement above the silt indicates Bois d'Arc, but the same residue with abundant *Foraminifera* or without *Foraminifera*, below the silt, indicates the Chimney Hill.

The Haragan and the Henryhouse are difficult to correlate separately due to their similarity. In most instances the tendency is to call the central part of the Hunton the Haragan. A lithologic study seems to show that most of the beds of the middle part of the Hunton in the Arbuckles is Haragan, but a study of the *Foraminifera* from subsurface samples indicates that the Henryhouse is the thicker there. The typical Haragan silt residue with Devonian *Foraminifera* at Dougherty can be correlated with the Haragan at Franks by means of the *Foraminifera* since the residue at Franks is not diagnostic. *Foraminifera* are rare in the Devonian, common in the Henryhouse, and abundant in the Chimney Hill. It is possible to identify the Haragan from the Henryhouse in the subsurface on the basis of the *Foraminifera*. Since the silts are common to both, no boundary can be

¹⁹ C. A. Reeds, "The Hunton Formation," *Amer. Jour. Sci.*, Ser. 4, Vol. 32 (1911), pp. 256-68.

———, *Nat., Hist.*, Vol. 26, No. 5 (1926).

———, *Oklahoma Geol. Survey Circ.* 14 (1927), p. 13.

²⁰ Ross Maxwell, Northwestern University, personal communication.

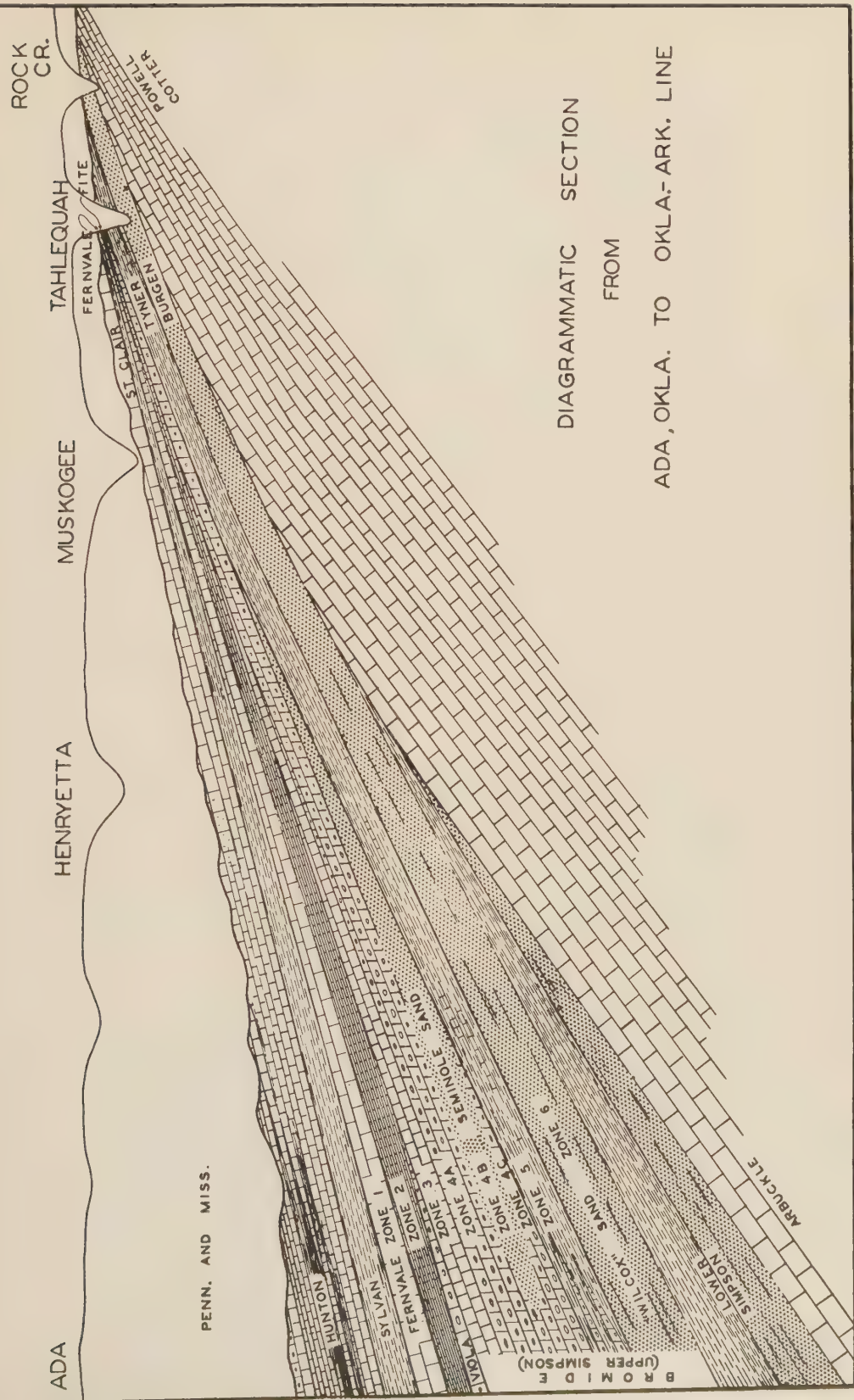


FIG. 12.—Diagrammatic section from Ada, Oklahoma, to Oklahoma-Arkansas line.

drawn where *Foraminifera* are absent. The Silurian forms are found high in the section of the subsurface which contains silt and it is concluded that the larger portion of the silt zone is Henryhouse. When *Foraminifera* are absent the same may be inferred. The Henryhouse thickens to the northward and changes laterally, as it approaches the Ozark region, into limestone with less silt. It is the writer's conclusion that the Henryhouse, by merging with the pink crinoidal member of the Chimney Hill, becomes the St. Clair pink marble of northeastern Oklahoma, where it is more than 200 feet thick. The Colton-Ellington well in Sec. 25, T. 12 N., R. 19 E., shows 160 feet of limestone with one per cent residue containing chert and glauconite at the base and Silurian *Foraminifera* 110 feet from the base. This is 25 miles from the surface occurrence of the St. Clair. The St. Clair contains fossils of Niagaran and Chimney Hill ages.²¹ The arenaceous *Foraminifera* are like those of the Henryhouse and Chimney Hill. The St. Clair of Oklahoma is correlated with the St. Clair near St. Joe and Batesville, Arkansas, and with the Girardeau, Edgewood, Brassfield, and Bainbridge of southeastern Missouri. Dunn has examined the arenaceous micro-fossils of the Silurian from southeastern Missouri, and which, with the ones which the writer has found, show that the Chimney Hill and Henryhouse are the equivalent of the previously named Missouri formations.²²

SYLVAN SHALE

The correlation of the Sylvan shale is a simple matter as the residues are 60-100 per cent gray or blue-green shale with occasional dolocasts. The brown, pitted, finely dolocastic layer at the base is a good marker for the top of the Fernvale. The Sylvan is herein called Richmond in age which is in accordance with general usage. It is equivalent to the Cason shale of Arkansas and to the Maquoketa of the Mississippi Valley.

FERNVALE AND VIOLA LIMESTONE

The residues of the Fernvale limestone ("Viola") are sufficiently constant to make it recognizable practically everywhere. The true Viola of the Arbuckle Mountains is much thicker than the subsurface sections of equivalent beds farther north due to the entrance of other beds into the middle and lower part of the section. The general surface section shows three zones. The upper 50-100 feet is coarse, crystal-

²¹ Ira Cram, "Geology of Cherokee and Adair Counties," *Oklahoma Geol. Survey Bull.* 40-QQ (1930), p. 23.

²² P. H. Dunn, "Silurian Foraminifera of the Mississippi Basin." Unpublished thesis, University of Chicago (1932).

line, gray limestone, Richmond in age, correlated as Fernvale, followed by 400-600 feet of fine-grained, somewhat cherty limestone of Trenton age, and at the base is 200 feet of dense lithographic limestone of Black River age. The Fernvale is the limestone commonly called "Viola" in the oil fields. The bed may be traced across the state, averaging about 40 feet in thickness. It is correlated with the Fernvale outcrop northeast of Tahlequah and the Fernvale of Arkansas and Missouri.

Zone 2 is the "Dense" limestone which is considered by some as the top of the Simpson and by others as the basal part of the "Viola" of the subsurface and the basal part of the true Viola of the Arbuckles.²³ The bed is persistent and can be traced to correlate with the Fite limestone of the Tahlequah section. The thickness is 2-10 feet in central and eastern Oklahoma. The position of the Fite over the Tyner at Tahlequah seems to indicate its relation to the Fernvale above rather than to the Simpson beds equivalent to the Tyner in central Oklahoma. A fact indicating the correlation of the Fite and the "Dense" limestone with post-Trenton beds is their persistence across the state as a unit with the Fernvale while the Trenton and part of the Black River are truncated placing the Fite unconformable to the Simpson formation.

The writer made a section along the new road cut near Franks, southeast of Ada, Oklahoma. The Fernvale was found to be about 100 feet thick, the Viola 300 feet, the Bromide 150 feet, and the McLish formation below. The 200 feet between zone 3 and the Fernvale of zone 1 represents the Trenton phase of the Viola which is not found in the subsurface section except in wells close to the border of the Arbuckle Mountains. The residues of the Viola in E. H. Moore's Wirick No. 1, Sec. 29, T. 2 N., R. 7 E., Tidal Oil Company's Halverson No. 1, Sec. 31, T. 5 N., R. 2 E., and Peckham and Harris' Adams No. 1, Sec. 11, T. 4 N., R. 1 E., can not be correlated with other zones, but when viewed as the Trenton part of the Viola, they readily fit the situation. The thick cherty section may thus be correlated with the middle cherty zone of the outcrop. Zones 1, 2, and 3 thin from 400 feet in the section at Franks to 145 feet in the Empire Oil and Gas Com-

²³ A. I. Levorsen, *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 763.

Ira H. Cram, *op. cit.*, p. 21.

G. D. Morgan, "Geology of the Stonewall Quadrangle," *Bur. Geol. Oklahoma Bull.* 2 (1924), p. 33.

F. C. Edson, "Ordovician Correlations in Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 968.

Luther H. White, "Subsurface Distribution and Correlation of the Pre-Chatanooga Series of Northeastern Oklahoma," *Oklahoma Geol. Survey Bull.* 40-B (1925), p. 17.

pany's Bonner well in Sec. 29, T. 5 N., R. 3 E., and to 120 feet in the Sinclair Oil and Gas Company's Gardner No. 1, Sec. 6, T. 4 N., R. 6 E. The decrease in thickness is caused by the disappearance of the middle Viola of Trenton age. The residues of zone 3 were found in the lower 100 feet of the Viola. The lower Black River part of the Viola is placed herein with the Bromide.

SIMPSON FORMATION

Zone 3 is considered herein as the top of the Simpson formation and as the upper Bromide. The zone is Black River in age. The upper part of the First dolomite of the subsurface section is probably the equivalent of the zone. The position of this horizon below the "Dense" limestone in the subsurface section and the position below the cherty zone of the Trenton in the surface section at Franks indicate to the writer that zone 3 is the equivalent of the Black River part of the lower Viola in the surface section.

Zone 4 is the middle Bromide and marks a distinct change in sedimentation and in residue. The zone is lithologically a dolomite but in places it has a large sand content. Levorsen states that the upper and lower dolomites which herein are included in zones 3 and 4 are indistinguishable in the southern part of Seminole County where the Seminole sand between them is absent.²⁴ They are easily defined by the use of residues. The zone between the top of the upper dolomite and the bottom of the lower dolomite remains relatively constant but where the sand is thick the dolomite is thin. The whole zone thins to about 50-60 feet north and northeast of Seminole with the sand occupying the major part of the zone. The Seminole sand in this area is definitely within the Second dolomite as defined by the residues. The writer is inclined to think that the lower part of zone 3 and the upper part of zone 4—that is, zone 4a—represent the First dolomite. Levorsen places the Seminole sand between the two dolomites but the residues show that it lies within the cherty zone 4. The separation by Levorsen is based on the position of the dolomites above and below the sand without regard to the cherty character. A sample log may indicate a dolomite and a cherty dolomite above the Seminole sand. According to the residues zone 4 includes the lower cherty part of the First dolomite. The chert horizon of zone 4c in the Second dolomite is not shown in the few wells where drilling has passed through the Seminole sand northeast of Seminole County. The sand of zone 4b occupies the interval, and ordinarily lies over

²⁴ A. I. Levorsen, "Geology of Seminole County," *Oklahoma Geol. Survey Bull.* 40-BB (1928), pp. 27-28.

the dolomitic green shale of zone 5. The zones as recognized in the southern part of the area are not identifiable farther north than T. 9 N., but correlation is possible by tracing the changes from well to well. The residue is all sand in T. 10 N., R. 7 E., and correlation by zones is not possible. All of the Simpson thins northeast due to the sedimentation and truncation, and correlation by residues is more difficult.

Zone 5 is correlated herein with the Tyner formation of northeastern Oklahoma. The Tyner is dominantly green shale with thin dolomite layers and a very distinct dolomite bed at the top, which is correlated with zone 4. Zone 5 though dominantly green shale has much more dolomite than the surface section and is entirely dolomite in some wells. The correlations of zone 5 and the Second "Wilcox" sand of zone 6 are so closely allied that they are discussed together. There are two lines of thought which lead to different conclusions. Both concepts are influenced by the age of the Tyner formation northeast of Tahlequah and the correlation of the Seminole sand. As the sands of the Ordovician are very similar the correlation is based on relations established by residues and other evidences from lithology and paleontology.

The following correlation is derived from consideration of Cram's²⁵ opinion that the upper and middle Tyner are Black River and that the lower Tyner is Chazy. He states that the "Wilcox" is a bed of sand which comes in to the west at the horizon of the basal Black River. This opinion would place the upper and middle Tyner as equivalent to the Bromide, and the lower Tyner and Burgen as equivalent to the Chazy part of the lower Simpson. Therefore, according to the writer, the green shale of zone 5 would represent the upper Tyner and zone 4 would represent the thin cherty dolomite above the Tyner at Tahlequah. The lower Tyner of Cram would be correlated with the green shale below the "Wilcox" and with the green shale and dolomite of the upper McLish. The Burgen would be correlated with the basal McLish sandstone and possibly include the Oil Creek. The McLish is Chazy; therefore, the Burgen and lower Tyner would be Chazy, which would place the Burgen as equivalent to the St. Peter, if the St. Peter is accepted as Chazy in age.

The second concept regarding the correlation of the Tyner and the Second "Wilcox" sand is based on relations which the residues show in regard to the Seminole sand. Most of the wells northeast of Seminole County do not penetrate below what is called the "Wilcox" sand, that is, the "Mounds Wilcox." The writer considers that the

²⁵ Ira H. Cram, *op. cit.*, p. 20.

sand called the "Wilcox" is probably the Seminole sand according to the residues of the beds above and below; therefore, the "true Wilcox" should be lower. The chert of zone 4 appears above the sand and if the sand were the "true Wilcox" sand there should appear above it the green shale of zone 5 which is absent. Where wells have been drilled below the so-called "Wilcox" sand in Okfuskee, Okmulgee, and Muskogee counties, there is a green shale below the sand. The writer would call this green shale the equivalent of zone 5. Accordingly, the thick sandstone encountered below the green shale zone is the "true Wilcox" or Second "Wilcox" which is thought to be Burgen in that area as no other sandstone occurs between the green shale and the top of the Arbuckle limestone. Thus, the Burgen and the Second "Wilcox" are thought to be equivalent and if the Second "Wilcox" is definitely Bromide in age, then the Burgen is Bromide and Black River in age. All of the overlying Tyner shale must be, therefore, Black River in age. This correlation would make the pre-"Wilcox" or the lower Simpson of the southern and central part of Oklahoma lense in between the Second "Wilcox" sand and the Arbuckle limestone, and account for the green shale and sand below the Second "Wilcox." These beds would be equivalent to the McLish and Oil Creek beds of Chazy age found in the Arbuckle Mountains. The foregoing correlation agrees with Ulrich's²⁶ contention that the Burgen is much younger than the Chazy and that it is probably Bromide. Since Cram is uncertain about the Chazy age of the lower Tyner, the foregoing correlation is suggested. The evidence as shown by the insoluble residues is so strong in the mind of the writer that he feels the correlation should be stated.

DEPENDABILITY OF RESIDUES

Due to the variability of the residues there are only a few which can definitely be depended on as diagnostic without other evidence. The silt aggregates of the middle part of the Hunton formation are dependable but they can not be used to distinguish the Haragan from the Henryhouse limestone. The *Foraminifera* are dependable for subdivision but they are not everywhere present. The siliceous replacement of fossils at the top of the Fernvale and the glauconite and chert content of the Chimney Hill limestone are reasonably infallible residues. A section of insoluble shale is always dependable unless the bed is lenticular. If the residue was not one of the foregoing it would be difficult to take two or three samples and place them in the section on

²⁶ E. O. Ulrich, personal communication to Ira Cram, *op. cit.*, p. 12.

the basis of residues alone. The identification of a sample would have to be based on the percentage of the residue, recognized overlying horizons, the knowledge that underlying horizons had not been passed, and on association. The upper Hunton cherts are similar to the lower Hunton cherts. As a whole they are fresh, pure white, vitreous, milky or opaline, while the Simpson cherts are buff, brown, drusy, sucrose, mottled, lusterless, and dolocastic. Where dolocastic chert is found one may be fairly certain that the chert came from below the "Dense" of zone 2. Such chert is rarely found above zone 4. The characteristics of sand grains are of slight value as a diagnostic residue but a small amount of sand mixed with chert, green shale, or large amounts of sand would have value. Generally the Hunton has very little sand; the Viola everywhere has sand but in small amount; while the Simpson has much sand in variable quantities according to the position in the section. The peculiar variegated sand of the Fernvale and the Cotter are fairly constant, but also occur in other horizons. Organic residues alone have no significance. It should be emphasized that few single types of residues are definitely diagnostic. It requires knowledge of lateral changes, paleontologic evidence, percentage of residue, and the association of the residues to make dependable correlation.

All of the series herein studied have suffered minor movements, as the unconformities described by Edson show.²⁷ The beds suffered greater movement during the post-Devonian uplift and the later Arbuckle-Ouachita orogeny. These combined movements and subsequent erosion and deposition have made the sedimentation very complex. The changes in gradation all seem to occur from the vicinity of Seminole County northward. The formations thin northeastward due to truncation and greater distance from the source of sediments of areas farther south.

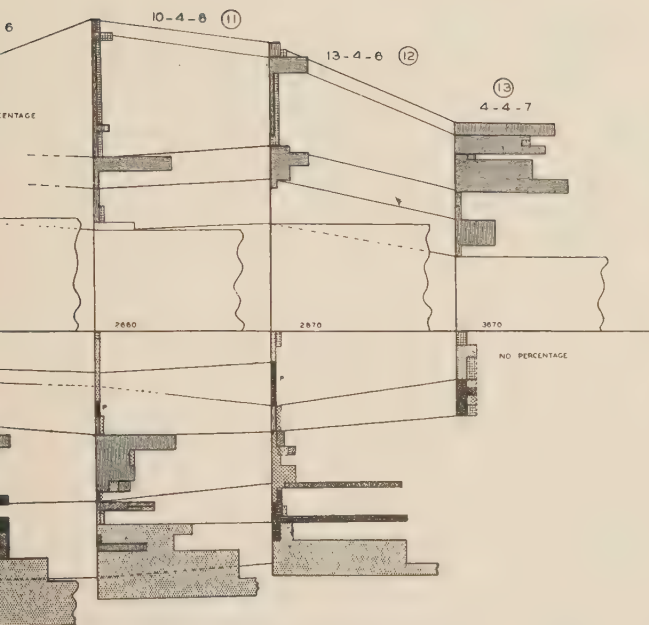
VALUE OF INSOLUBLE RESIDUES

The use of insoluble residues does not replace lithologic examination but is a supplement to it. Characteristics of samples which are obscured by the volume of the cuttings and by being embedded in the cuttings are liberated, concentrated, and exposed by the solution of the matrix and the diminution of the volume. *Foraminifera*, some types of chert, dolocasts, pyrite, fossil replacements, authigenic crystals, detrital igneous fragments, and silt aggregates are not commonly seen when they are embedded or mixed with the general sample.

²⁷ Fanny Carter Edson, "Tectonische Phasen in der Pra-Mississippi Formationen der Mid-Continent Region," *Geol. Rundschau*, Vol. 22 (1931), pp. 11-19.



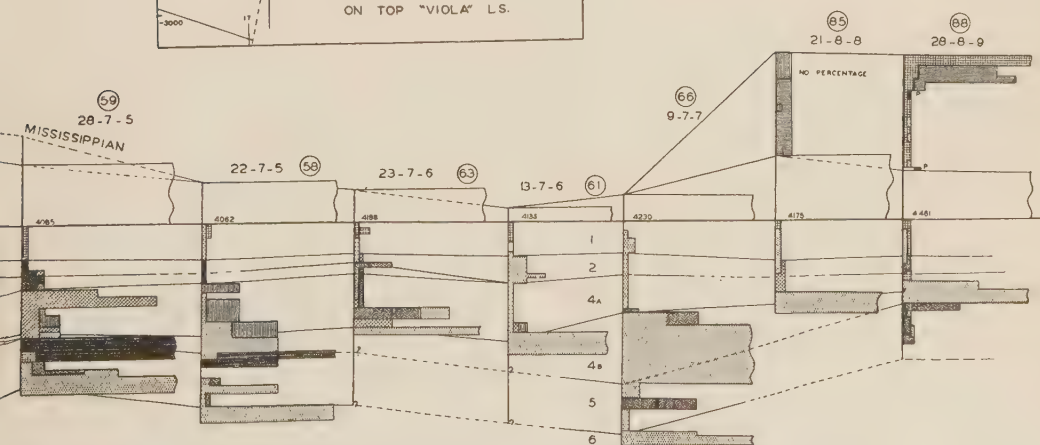
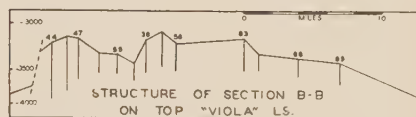
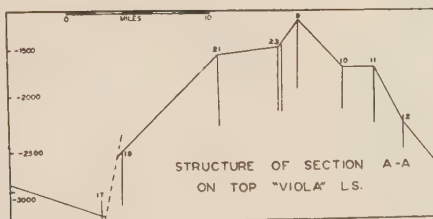
FIG. 13.—East-west cross sections AA' and BB', showing graphic presentation of stratigraphy.



LEGEND

- DENSE, CRYSTALLINE, OR ROUGH WHITE CHERT
- DRUSY, GRANULOID, DENSE, DOLOCLASTIC, OR CRYSTALLINE BROWN OR BUFF CHERT
- SAND GRAINS
- SILICIOUS ORGANIC REPLACEMENT
- WHITE, GREY, OR BUFF SILT
- SYLVAN SHALE (NO ANALYSIS)
- GREEN SHALE
- BROWN, GREY, ETC., SHALE
- GLAUCONITE OR PYRITE

SCALE



tion obtained by examination of insoluble residues. Location of sections shown in Figure 1.

Residues have value in the correction or confirmation of lithologic determination. In several instances the top of a formation established by lithologic examination has been placed 20-30 feet lower than where the residues indicate it to be. A lithologic change should be reflected by a change in the character of the residue. A small amount of sand residue at a depth of 4,435 feet in the Gypsy Oil Company's Johnson well, Sec. 7, T. 7 N., R. 4 E., changed abruptly to a residue of 5, then 20 per cent of chert. The top of the formation, as shown by lithology, was 4,455 feet. The contact might be shifted therefore up 20 feet to the point of change in residue.

The structures below the major widespread unconformity at the base of the Chattanooga shale are essentially the structures which make possible oil occurrence in large quantities. The key beds for determining such structures are limestones or well defined shales. The identification of such limestones is greatly facilitated by the use of residues.

The Fernvale limestone and the Hunton limestone may generally be distinguished but are often confused with each other even by the best geologists. White comments as follows.

The lithologic similarity of drill cuttings from the Fernvale and the Hunton is so strong that the two are not easily distinguished on this basis. Frequently such a determination is not possible until the Sylvan shale or the Simpson formations have been identified.²⁸

Levorsen²⁹ comments similarly. Residues are invaluable when such a situation exists. The Hunton and the Fernvale residues are so different in most places that a few samples will serve for the purpose of identification. If the distinction of these two beds was the only result of this study, the investigation would be justified. For example, if a limestone at a depth of 3,000 feet was identified as the upper Hunton, the lack of an oil-producing structure might be indicated (Fig. 14). If the same limestone was identified as the Fernvale, it might indicate a possible oil-producing structure. If the bed was determined as the lower Hunton, a structural "high" might still be indicated, but not as large a "high" as where the Fernvale was encountered. It is important, therefore, to know whether the limestone encountered is Hunton, Fernvale, or some other limestone.

The Hunton is a producing horizon in many places and it is im-

²⁸ Luther H. White, *op. cit.*, p. 21.

²⁹ A. I. Levorsen, *op. cit.*, p. 21.

portant to know if the producing bed has been encountered. The writer feels that it is possible to tell whether the sample came from the upper, middle, or lower part of the Hunton. The identification by residues would make it unnecessary to drill into the Sylvan shale before confirming the identification made from lithologic examination.

Some objection might be raised concerning the use of secondarily formed residues. Ground-water changes would tend to act more or less uniformly along the same bed unless the constituents of the bed changed or unless some local factor affected conditions. Such changes would grade away from the point of localization or from the point where the change in constituents began. Such gradations could be noted and the correlation continued. With such conditions long-distance correlation would be risky.

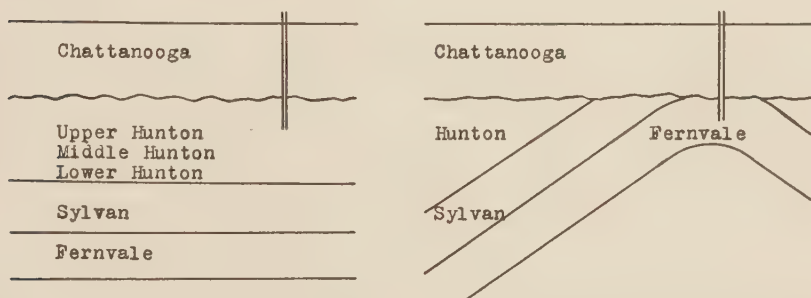


FIG. 14.—*Left.* Diagram showing absence of structure because limestone below unconformity was called Hunton. *Right.* Diagram showing presence of structure because limestone below unconformity was called Fernvale.

One of the most valuable results of this method of study is the liberation of arenaceous *Foraminifera* from the enclosing matrix. Chief dependence is generally put upon fragments of megascopic fossils or discernible microscopic fossils existing in the cuttings.

Unbroken organisms replaced with silica would have as much value as any other fossils. However, in well cuttings organisms are generally in fragments. Embryonic forms and microscopic organisms of all kinds may be used for correlation as they are too small for the drill to destroy. However, they are obscured by the volume of rock fragments unless concentrated by solution of the matrix, though at the same time many of the forms are dissolved. There is not sufficient information on the casts of interiors to make them usable. Siliceous replacement of fossils is considered merely as a type of residue rather than of paleontologic importance in this study.

Residues for long-distance correlation in Oklahoma are not satisfactory except for certain beds which have a constant residue. The Hunton formation has individual beds which have a more or less constant residue and broad distribution. The Fernvale is also recognizable but the Simpson, though it may be divided into zones which themselves are persistent, has residues which are variable and difficult to recognize unless the lateral variations and changes are carefully observed. These statements are based on the study of the Oklahoma section where strata grade laterally, are lenticular, and show alternation in composition. The fluctuating seas of the Simpson time make the sediments so variable that with the further complication of the subsequent orogenies and effects of ground-water circulation, the task of unravelling the sedimentation is colossal. McQueen has had excellent results with Cambrian and Ordovician beds in Missouri, aided by the more constant vertical and horizontal similarity of the strata studied. It is possible that the use of residues for long-distance correlation will be valuable where only general characteristics are used and where one wishes to know only the age of the bed and not a particular subdivision. Where strata of different age exist that are relatively constant in lithologic character and similar in appearance, long-range correlation may be successful as the residues may be expected also to be relatively constant. In regions in the interior of the United States, beds far from the Paleozoic coast lines should show very little gradation. Such lateral changes that do occur may be observed from a few intervening samples. For a distance of 10 miles correlations should be possible, but for 100 miles many intervening localities should be available.

The use of residues is not restricted to the laboratory. A gallon of acid and 4 or 5 tumblers may be carried along with the microscope in an automobile during field work, and if a need for a residue occurs, the material for solution and examination is available. Heat from the boiler at a drilling well or from the engine-head of the automobile may be used for rapid drying and examination made at the location.

Every stratified bed is deposited under a definite sedimentary environment and one task of the geologist is to learn of such environments. Detrital material will be deposited indigenous to the strata. If the environment changes, the detritus will be different in amount and character, and the residues will show such changes. A change in the source of the detritus would cause the residues to be different. Water circulation and changes occurring after lithification of the strata would likewise be reflected in the type of residue. These

changes, if large enough, might be observed in the lithologic examination of samples, but only the study of residues would show the small changes after the obscuring matrix has been removed.

The use of insoluble residues is limited to calcareous beds. It would be of little value to study shales and sandstones except in their relation to associated limestones. Although the Cretaceous and Tertiary beds contain abundant *Foraminifera* for correlation purposes, some of the forms are long-range and it should be possible to determine the relations of beds containing such forms more closely by the use of insoluble residues.

